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Time-Frequency Analysis of Functional EPI Time-Course Series

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PURPOSE:

The objective of this work is demonstrate the use of time-frequency distributions in extraction of information from fMRI time-series data that would not be possible using the Fourier transform.

INTRODUCTION:

The Fourier transform (FT) forms a one-to-one relationship between the time domain and the frequency domain. When applied to the time-series of EPI fMRI data, it gives a description of the frequencies occurring in the brain activity. However, the FT has a serious drawback, it does not tell us at what time the frequencies occur. This drawback of the Fourier Transform is overcome by using time-frequency distributions. Time-frequency distributions use a joint function of time and frequency from which one can determine the frequency which occurred at a given time and vice-versa. In this study the EPI fMRI time-course is analyzed using different time-frequency distributions and more detailed information regarding the brain activity is extracted.

METHODS:

Time-frequency distribution is the estimation of the energy distribution of the signal in the time-frequency plane. A one-dimensional signal either in time or frequency is mapped into a 2-D function of time and frequency. In this work, three time-frequency distributions (Short-time Fourier transform, Wavelet transform and Wigner-Ville distribution) are used to analyze the EPI fMRI time-course series.

The short-time FT $STFT(t, f)$ of a signal $z(t)$ is calculated by applying a sliding window $\tau^*(t'-t)$ to a part of the signal. The FT of the windowed signal yields the $STFT$, which can be represented mathematically as

$$STFT(t, f) = \int [z(t') \gamma^*(t' - t)] e^{-j2\pi f t'} dt'$$

Because, the $STFT$ uses a fixed window, there exists a fundamental resolution trade off. Time resolution can only be improved using a short window at the expense of frequency resolution and vice-versa.

The Wavelet transform (WT) overcomes the fixed window problem of the $STFT$ by using a variable analysis window. The WT uses a long window at low frequencies and short windows at high frequencies, thus maintaining a constant relative frequency analysis. The WT of a signal is defined as

$$WT(t, f) = \int z(t') \left| \frac{f}{f_0} \right|^{1/2} \gamma^* \left[\frac{f}{f_0} (t' - t) \right] dt'$$

where $\tau(t)$ is the "analyzing window" centered around $t=0$ in the time domain. The value of f_0 is equal to the center frequency of $\tau(t)$.

The Wigner-Ville distribution (WVD) is the most widely used quadratic time-frequency distribution. The WVD of a signal $z(t)$ is given by

$$WVD(t, f) = \int z(t + (1/2 + \alpha)t') z^*(t - (1/2 + \alpha)t') \exp^{-2\pi j f t'} dt'$$

For this study, the images were obtained using a GE 1.5 T Signa scanner using a three-axis balanced-torque head gradient coil and a shielded endcapped quadrature transmit/receive birdcage rf coil. A time course of 200 echo-planar images was acquired, with 10 images of finger tapping alternating with 10 images of "rest".

RESULTS:

The time-frequency plot of the time-course data set obtained using the WVD is shown in Fig 1, where one can track the frequencies as they evolve in time. The magnitude of the frequency components can also be studied as a function of time. It is seen that the magnitude of the frequency spectrum is maximum at the second tapping period after which it decreases. It is also observed that there are some frequencies which are present in the resting state only.

CONCLUSIONS:

In this study it is seen that the time-frequency distributions can dynamically track the spectral changes occurring as a function of time. The WVD method is computationally efficient relative to the other methods, and the linear 2-D display seems easier to interpret. These methods are now being applied to longer time course data sets, in order to study habituation, and also to data sets where the frequency of task activation is systematically varied.

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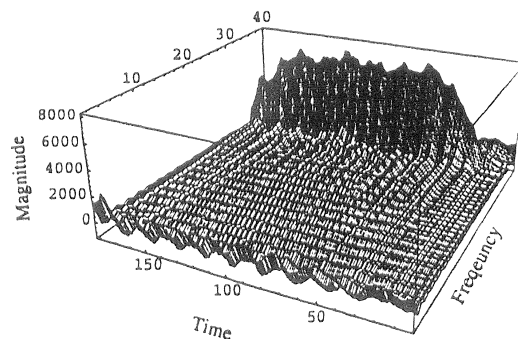


Figure 1. WVD of Functional EPI Time-Course Data Sets